

# Chapter 4

## THE CHEMICAL WARFARE THREAT AND THE MILITARY HEALTHCARE PROVIDER

ERNEST T. TAKAFUJI, M.D., M.P.H.\*; AND ALLART B. KOK, M.S.†

---

### INTRODUCTION

### THE CHEMICAL THREAT AND ENEMY CAPABILITY

#### THE STATUS OF CHEMICAL PROLIFERATION

- Chemical Warfare Capabilities of Nations
- International Agreements and Verification
- Terrorism

### MILITARY CHEMICAL AGENTS

#### TACTICAL AND STRATEGIC USE OF CHEMICAL WEAPONS

- Chemical Agent Delivery Systems
- Physical Properties of Chemical Agents
- Strategic Concerns in the Use of Toxins
- Choice of Agent and Delivery System
- Detection and Protection

#### RESPONDING TO THE THREAT: MANAGING CASUALTIES

#### FUTURE CONFLICTS IN A CHEMICAL ENVIRONMENT

### SUMMARY

\*Colonel, Medical Corps, U.S. Army; Commander, Walter Reed Army Institute of Research, Walter Reed Army Medical Center, Washington, D.C. 20307-5011

†Science Applications International Corporation, Joppa, Maryland 21085

## INTRODUCTION

Some military medical personnel view the specter of chemical warfare with fear and repugnance. The images of clouds of poisonous chemicals; contaminated terrain and equipment; and the need to work in protective masks and hot, cumbersome overgarments are intimidating even to well-trained soldiers. But for medical personnel there is an added factor: the fear of the unknown. The milieu of the chemical battlefield is especially alien since little in the normal professional practice of most military medical personnel has any resemblance to the management of casualties of chemical warfare.

Although military strategists might view chemical warfare agents as simply one of the means to immobilize or destroy an enemy force, others may view such weapons as abhorrent extensions of conventional warfare. Be that as it may, it is not the intent of this chapter to justify the use of chemical weapons in battle but rather to relate the use of chemical warfare to health issues. Although current policy of the United States government prohibits using chemical weapons against an adversary, this policy is not shared by all nations; therefore, to be effective, military medical personnel must be knowledgeable and trained.

To the military healthcare provider, chemical warfare crosses over the lines of strategic and tactical purposes, where victory may be viewed as full justification of

- the means;
- the difficult challenges associated with the identification, treatment, and prevention of specific injuries and illnesses in a deliberately contaminated and highly stressful environment;
- the psychologically demoralizing effect that chemical weapons may cause; and
- the personal ethical concerns that many medics may have about suffering resulting from the deliberate use of weapons specifically targeted to the human element.

Although healthcare providers are usually not involved in the political or military decisions surrounding use of chemical weapons, they must be

- prepared to deal with the military and civilian casualties resulting from use of such agents;

- cognizant of what constitutes a chemical threat and the military tactics that could be employed against the force, since they may be called on to render advice to their commanders from an individual and public health perspective;
- familiar with the acute and chronic medical effects of chemical agents in order to plan appropriate medical support; and
- fully knowledgeable of the diagnostic tools available to identify specific etiologic agents to which their patients may have been exposed and the most effective methods of intervention and prevention.

The “chemical threat” can be defined as a statement of the who, what, when, where, and how of chemical warfare. The threat may involve single or multiple chemical agents—not only the classic chemical agents specifically developed for military applications (ie, chemicals that had been weaponized by the 1950s), but also highly toxic industrial compounds that could achieve the same objective. Military medical care providers need to be well-informed of the current chemical warfare threat in environments in which they may be called to serve. They should also be familiar with sociological and psychological factors motivating the use of such weapons in a battlefield or terrorist scenario.

Chemical warfare agents do not need to be lethal to be disruptive. It is not difficult to envision a scenario where medical practitioners may be the first to observe and recognize the effects of chemical exposure—in the absence of warnings from the intelligence community. Few physical indicators of chemical attack may be evident, other than the initial observation of unusual signs and symptoms. This scenario could occur when new agents, for which there may be no environmental monitoring, are used. An increased incidence of symptoms consistent with nerve, vesicant, blood, or respiratory agent exposure should raise immediate suspicion of poisoning, even among presumably protected troops. The possibility of combined use of chemical and biological warfare agents should also be considered.

Offensive use of chemical agents continues to be attractive to some nations, for chemical agents can be dispersed over large areas and can eventually penetrate even the most well-defended positions.

They can be employed against specific targets, including headquarters control centers and, depending on the agent or combination of agents used, the effects can be immediate or delayed incapacitation, disorientation, or death. The psychological impact is ever-present, even among well-seasoned and -trained troops equipped with full barrier protection. Many of the more common classic chemical agents—which are generally believed favored by possessor states—can be produced inexpensively and quietly, and they can be stored indefinitely. Their minimal cost has earned chemical warfare agents the appellation “the poor man’s atomic bomb.”

Although treaties dealing with control or elimination or both of classic chemical weapons may

reduce the danger that chemical warfare agents will ever be used, difficulties in verification and in controlling the manufacturing, acquisition, and storage of precursor chemicals make chemical war a continuing concern for the U.S. government. Chemical proliferation has not decreased. Saddam Hussein’s use of chemical warfare against the Kurds in 1988 demonstrates how readily such weapons can be used, even within the confines of one’s own country. The 1994 and 1995 incidents involving the Aum Shinrikyo cult’s use of sarin (ie, the nerve gas GB) to cause fatalities and disruption in Matsumoto and in the Tokyo subway system demonstrate how easily a terrorist organization can quietly produce and use a classic chemical warfare agent.

## THE CHEMICAL THREAT AND ENEMY CAPABILITY

The term “chemical threat” centers on enemy capability. The term capability encompasses<sup>1</sup>

- the availability and supply of specific agents;
- the delivery system or systems that would be used in different battle situations;
- the facilities to produce these agents and munitions;
- plans and procedures for the employment of such weapons, including training for the delivery and handling of such weapons;
- protection of a nation’s own forces against specific agents; and
- the national will to use such weapons.

Although international disapproval may discourage a country from using chemical agents, the aggressor nation may finally decide that protecting its national interests and survivability is more important.

An active research and development program on agents and delivery mechanisms supports the notion of operational use. Chemical warfare munitions are particularly important, for weapon systems must deliver agent to the target and distribute that agent with maximal effective contact. Successful chemical warfare munition use must also be combined with meteorological assessment capabilities. For example, sarin, a highly volatile agent with little persistence on the ground, must be delivered under specific environmental conditions and in a timely manner that would allow greatest human contact for optimal effectiveness. Ideal conditions and carefully developed delivery systems are not

always necessary, however: Iraq simply pushed containers of chemicals out of aircraft during the Iran-Iraq War.

Ordinarily, an enemy with chemical warfare capability will be well equipped for chemical warfare protection; they will have defined procedures on decontamination, individual and equipment protection, and detection and surveillance. Since chemical warfare agents are nonselective in their human targets and dangerous for the user as well as the enemy, they require that offensive and defensive programs be developed simultaneously. Special military teams (eg, logistical, medical, and chemical corps teams trained to operate in a chemical environment) and the ability to monitor meteorological conditions are characteristic of nations with offensive or defensive programs or both. In the assessment of enemy capability, chemical stockpiles, production capacities, and the control of use are evaluated when an offensive or a defensive posture is being determined. This is not easily accomplished, since industrial plants that are manufacturing products with peaceful applications may be capable of having their manufacturing processes redirected toward chemical agent production.

In a changing world, where the traditional East-West conflict has subsided in the face of steadily increased chemical agent proliferation among many Third World nations, the chemical threat appears to be increasing from smaller nations or political splinter groups with little or no sophisticated chemical warfare industrial capability. Hence we must be prepared for chemical agent attack from terrorist elements, and for crude delivery systems

as well as highly developed offensive chemical warfare operations. Political instabilities and changes toward radicalism only heighten the dangers and concerns that defensive programs can be converted to offensive efforts, and, although clas-

sic chemical warfare agents are harder to produce and stockpile in large quantities without being noticed, small amounts of some older agents can be manufactured in relatively crude laboratories and used to create disruption.

## THE STATUS OF CHEMICAL PROLIFERATION

Until 1987, when the Soviet Union admitted for the first time that it possessed an offensive chemical warfare capability, the United States was the only publicly declared state capable of conducting chemical warfare. In July 1988, long after a United Nations commission had confirmed Iraqi use of chemical agents (mustard and nerve agent) against Iran (a flagrant violation of the 1925 Geneva Protocol, which Iraq had signed in 1931), Iraq also declared an offensive capability. Apart from the three nations mentioned, estimates of countries that possess chemical agents, and the nature of the agents they possess, must rely on sources other than official statements. Given this, it is not surprising that published lists of states with chemical warfare capability have varied widely. However, a key trend in chemical warfare capability over the past 20 years is evident: an increasing number of states are likely to possess such weapons.

### Chemical Warfare Capabilities of Nations

The magnitude of world interest in offensive chemical warfare capability was made evident during an open hearing of the U.S. Senate Committee on Governmental Affairs on 9 February 1989, when William H. Webster, former Director of Central Intelligence, presented a list of weapon states. The confirmed chemical weapon possessor states were the United States, the Soviet Union, Iraq, and Iran. France has subsequently declared a chemical warfare capability, bringing the number of possessor nations to five. Countries currently suspected of possessing chemical weapons or in the process of acquiring them are identified in Exhibit 4-1. Several other nations are being closely monitored for signs of an acquisition program.<sup>1</sup>

An article in the March 15, 1991, issue of *The Washington Post*<sup>2</sup> described the latest annual report of the Office of Naval Intelligence, listing 14 nations with "an offensive chemical-warfare capability"; the list included Egypt, Israel, Pakistan, and South Korea, 4 nations that receive large quantities of military aid from the United States. Four additional nations (Saudi Arabia, Indonesia, South Africa, and Thailand) were purported to possibly possess such

a capability, and then more nations were believed to be in the process of developing or seeking to develop chemical weapons. Interestingly, this list conflicts with a U.S. Department of Commerce list that does not list the strong trade partners of South Korea, Indonesia, and Thailand as having definite offensive capability. In a 1993 U.S. House of Representatives Committee on Armed Services report, 31 nations were mentioned as possessing or having the ability to develop offensive chemical weapons.<sup>3</sup>

Offensive chemical warfare capabilities depend on such factors as chemical agent quantities, types of agents weaponized, modes of delivery, doctrine for use, means of self-protection, and other considerations that together characterize the total threat posed by a chemical warfare-capable state. Such detailed analysis of the threat posed by each possessor state is beyond the scope of this chapter, and interested readers should review classified and unclassified sources for each nation.

A general idea of the classic agents was provided by the Soviets when chemical armaments were displayed for the first time to Western visitors in 1987, and later by Iraq when its arsenal was inspected. The Soviets showed a wide variety of chemical weapons delivery systems that could carry blistering agents (mustard and Lewisite), nerve agents (soman, sarin, and VX) or the riot control agent CS (2-chlorobenzalmalononitrile). Some of these agents were thickened to increase battlefield deposition and persistence (see Military Chemical Agents, below).

United Nations weapons inspectors, on gaining access to Iraq's arsenal in 1991, found primarily sulfur mustard, sarin (and a sarin analog, GF), and another nerve agent, tabun.<sup>4</sup> The Iraqi chemical warfare development program was well developed, and included experimentation with VX. Far beyond pushing barrels out of helicopters, the sophisticated Iraqi chemical weapons delivery systems now included aerial bombs, artillery rockets, artillery shells, cluster bombs, and mortars. Seventy-five chemical warfare ballistic missile warheads were also discovered, filled with sarin/GF mixtures or binary nerve agent (in binary systems, two individually less-toxic reagents are mixed in the weapon at the time of use to form the agent).

**EXHIBIT 4-1**

**CHEMICAL WARFARE CAPABILITIES OF NATIONS**

Exhibit 4-1 is not shown because the copyright permission granted to the Borden Institute, TMM, does not allow the Borden Institute to grant permission to other users and/or does not include usage in electronic media. The current user must apply to the publisher named in the figure legend for permission to use this illustration in any type of publication media.

Adapted with permission from Burck G, Flowertree CC. *International Handbook on Chemical Weapons Proliferation*. New York NY: Greenwood Press; 1991: 164-165.

Prior to its destruction, Iraq's primary chemical warfare agent production facility at Al Muthanna, Iraq, produced thousands of tons of agent. The complex included well-built, underground, bunker-type complexes, billed as sites for pilot plants for pesticide production but apparently capable of VX production. Another facility served as an inhalation chamber for making lethality estimations. Two other sites were built at Fallujah, Iraq, to make chemical precursors for use at the Al Muthanna plant, although one of the Fallujah plants, while containing stored agent precursors (for VX, GB, and HD [mustard]), was adapted for malathion pesticide formulation. These examples illustrate why it can be difficult, with limited inspections or information from open declarations, to distinguish facilities designed for the chemical industry from those for munitions generation.

These chemical manufacturing facilities are only part of Iraq's chemical warfare capability. Iraq, like Libya, also invested heavily in the development of

facilities for the production of indigenously generated delivery components.

The current development of offensive chemical warfare capabilities varies among the possessor states and is now particularly dynamic. First, the United States and Russia, which has inherited the chemical weapons arsenals of the Soviet Union, have embarked on a program to radically reduce the chemical agent stocks held by both sides by the late 1990s. Second, in January 1992, some 125 nations signed a treaty, formulated over 24 years, at the Chemical Weapons Convention in France, calling for the prohibition of the production, storage, use, and transfer of chemical weapons; and for the elimination of chemical warfare arms and production facilities.<sup>5</sup> By January 1993, 130 nations had signed the treaty, and more are expected to follow.

During the 1980s, some nations vastly increased their development of offensive chemical capabilities, particularly in the Middle East, where chemical warfare capability substitutes in some respects for a nuclear weapons capability. A rapid transition

from nascent development programs to full weaponization occurred in Iraq, Syria, and Libya, and Iraq unleashed chemical weapons against Iran in 1984. Iraqi use of mustard and nerve agents constituted the first full-scale use of chemical weapons in battle since World War I.

The effective elimination of the Warsaw Pact and the dissolution of the Soviet Union have greatly diminished and reconfigured the overall chemical threat from that part of the world. The exportation of Soviet technology has been a continuing process, and it is likely that the chemical weaponry and technological know-how was well disseminated to developing nations. The Russians have declared a chemical agent stockpile of about 40,000 tons (higher than the 30,000 of the United States).<sup>6,7</sup> As of 1996, it appears that all of the former Soviet Union's chemical weapons containers and munition components are maintained at seven sites in Russia. As is done in the United States, most of the agent is primarily stored in nonweaponized containers; the weaponizable portion appears to consist entirely of soman- and VX-like nerve agents, sulfur mustard, and Lewisite. Mixed preparations are common in the arsenal. With all chemical warfare agents under a single central control, the possibility of unauthorized weapons proliferation by former Soviet border nations, several of which are politically unstable, should be greatly diminished, although the possibility of chemical weapons proliferation through theft under a climate of economic turmoil remains real. Uncertainties regarding dispersal, and management procedures concerning that stockpile, suggest that some chemical weapons could be lost while awaiting destruction.<sup>8</sup>

The Soviet military appeared to have invested considerable effort toward the development of forces capable of operating in a chemical warfare environment.<sup>9</sup> According to the U.S. Defense Intelligence Agency, Soviet facilities associated with the production, testing, and storage of chemical or biological agents or both continued to expand through 1987.<sup>10</sup> Today, a variety of chemical warfare delivery systems are available to Russian military forces, including artillery, bombs, free rockets, ballistic missiles, and cruise missiles.

The origin and nature of the overall chemical agent exposure threat to U.S. troops changed considerably during the 1980s. Although the threat of chemical warfare confrontation with former Warsaw Pact nations appears eliminated, the proliferation and use of chemical warfare agents within unstable sectors of the Third World has raised great concern regarding the potential for future use of

chemical warfare agents both with respect to open conflicts and to terrorist activities. For Third World nations, chemical weapons are less expensive and easier to acquire, and are a more credible threat than nuclear weapons. The adaptation and incorporation of chemical agent-containing munitions to conventional or missile delivery systems can give a weaker nation a military threat with which to counterbalance that of neighbors that possess a greater conventional capability.

Nations may initially acquire a limited chemical warfare capability through the transfer or purchase of bombs or artillery-compatible chemical warfare shells. In some cases, unweaponized agent may have been transferred.<sup>11</sup> Alternatively, nations may invest in the development of chemical industries that involve the manufacture or acquisition of chemical precursors or intermediates. In this way, wealthier nations (eg, Iraq, Libya) or those under a strong, perceived threat (eg, Syria) may increase their chemical warfare potential by acquiring the technology and facilities to synthesize agents and incorporate them into munitions that are compatible with existing or newly acquired delivery systems. Industrial compounds such as organophosphates (pesticides), phosgene, chlorine, and cyanide are not difficult to obtain.

Economic factors such as wealth, profit incentives, international debt, and isolation can contribute to the proliferation of chemical warfare capabilities. For example, oil-rich nations ruled by dictators (eg, Libya, Iraq) have been able to use their profits to acquire expensive delivery systems such as ballistic missiles and long-range bombers, along with associated support aircraft.<sup>12,13</sup> When shunned by major arms-systems producers such as the United States, Britain, France, and Russia, the oil-rich nations have approached other Western sources or those in less-developed nations, some of them deeply in need of foreign capital, such as Brazil, Chile, Argentina, Yugoslavia, Israel, Egypt, North Korea, or the People's Republic of China.<sup>12-16</sup>

Inevitably, there is a trickle-down effect in the arms world, as aging munitions and weapons systems are replaced and move from the major weapons producers to their Third World client states, and from the latter to other nations. For example, the Soviet Union probably supplied a chemical warfare capability to Egypt,<sup>11</sup> which, in turn, first supplied Syria,<sup>15</sup> which, in turn, supplied Iran.<sup>16</sup> It should be noted that some weapons systems, especially from the former Eastern Bloc countries, were designed to operate in a chemical warfare theater.<sup>9</sup> As noted earlier, a defensive capability is generally held to

be prerequisite to an effective offensive chemical warfare capability.

The profit motive has driven many private industries to supply Iraq and Libya with technology, infrastructure, and chemical precursors for the synthesis of nerve and blister agents in large volume, and the manufacture of artillery shells and bombs required for their delivery. Until recently, West German government export control was minimal, resulting in the involvement of some 86 German firms in Iraq's development of chemical and nuclear weapon capabilities and ballistic missile design. A considerable number of companies in Austria, Britain, France, Italy, Switzerland, and the United States were also involved in these efforts. Products included chemical agent production plants and precursor compounds, computer systems, machine tools, casting and milling technology and facilities, weapon and ammunition production facilities, missile technology and "super gun" components.<sup>16</sup> Commercial dissemination of chemical warfare capabilities will be a continuing problem in the years ahead.

### International Agreements and Verification

Despite such uncertainties, a chemical weapons reduction agreement<sup>17</sup> was reached in 1990 between the United States and the Soviet Union that will (1) effectively stop chemical weapon production and (2) reduce each nation's chemical agent stocks to a value of 5,000 metric tons by the year 1999 (by the end of the year 2002, this number will fall to 500 tons). Destruction of the remainder is contingent on a commitment for similar, total chemical warfare stock elimination by other chemical warfare-capable nations.<sup>18,19</sup>

On May 13, 1991, U.S. President George Bush further advanced his 1989 plan before the United Nations to destroy 98% of the U.S. stockpile in the first 8 years under a new, proposed treaty. Under its conditions, he pledged (1) to destroy all U.S. chemical weapons within 10 years and (2) never to use chemical weapons again.<sup>20</sup> (However, anticipated difficulties in chemical weapon demilitarization and destruction may prolong the presence of chemical weapon depots.) This message sent a clear challenge to other powers to eliminate chemical weapons. The United States ratified the treaty on 24 April 1997, which was a few days before the treaty went into effect. Although signed by nearly 160 nations, it must still be ratified by most of those nations. The treaty still leaves in doubt the development and use of chemical warfare agents by developing nations or nonsigners of such agreements

(most notably Libya, Iraq, and North Korea). Chemical warfare treaty ratification by nations such as Iran, given the behavior of its neighbor, Iraq, may prove to be understandably difficult in the short term.

Reluctance by possessor states to employ chemical weapons, which could be termed "the chemical warfare threshold," has seemed to be relatively high since World War I. However, the Iraqi precedent, the ineffective world response to Iraq's use of chemical warfare, and the perceived effectiveness of this use all suggest that the chemical warfare threshold has been substantially lowered. The growing list of states motivated, for reasons of offense or deterrence, to develop relatively low-technology, low-cost weapons of mass destruction greatly increases the likelihood that military personnel will have to contend with casualties of chemical warfare.

Finally, the problem of verification of treaty compliance continues to be difficult even with on-site inspections. The former Director of Central Intelligence, William H. Webster, stated on 15 October 1988:

After all, any country with a petrochemical, pesticide, fertilizer, or pharmaceutical industry has the potential in terms of equipment, raw materials warfare, and technical expertise to produce some chemical agents. Without direct access to such facilities, it is nearly impossible to know whether activities being undertaken are of a commercial or a military nature.<sup>21(p9)</sup>

This concern was reiterated in congressional testimony following the Persian Gulf War.<sup>18</sup>

### Terrorism

Finally, no threat assessment would be complete without addressing the terrorist dimension. Terrorism may derive from clandestine, state-directed initiatives<sup>22</sup> or, more commonly, from small splinter groups with special interests or agendas. Groups with training and financial backing need only to set up small laboratories to make chemical or biological warfare agents. For example, while investigating Red Army faction activities in 1980, French police uncovered in an apartment a clandestine laboratory capable of producing botulinum toxin.<sup>23</sup> This suggests that state-sponsored terrorism could serve as a conduit for the testing of the products of rapidly emerging biotechnology techniques. It also places healthcare providers in a position in which they may be the first to encounter and evaluate the dangers of new and emerging threats. Also notable is the successful manufacture of a military nerve

agent by able university students recruited by Aum Shinrikyo. Psychological manipulation and religious zeal were combined to support the terrorist actions of this organization, which was well funded by its members.

Chemical and pharmaceutical industries continue to spread around the world, providing unsponsored terrorist groups access to precursors and chemicals. Compounds such as chlorine, phosgene, and cyanide are commonplace, and theft of such materials has been reported.<sup>24</sup>

In addition to terrorist actions, accidents will occur as manufacturing with potent industrial chemicals becomes widespread. Although industrial compounds are not traditionally classified as chemical agents, they are lethal and potent (eg, the disaster in Bhopal, India, which is discussed later in this chapter). Poor economic conditions may also promote theft of agents and their chemical precursors and illegal transfer of weapons—not only by international brokers but also by industrial workers.

## MILITARY CHEMICAL AGENTS

Military chemical agents are characterized according to several features. Among them are the nature of their use, their persistency in the field, and their physiological action. Toxic chemical warfare agents are capable of producing incapacitation, serious injury, and death. These agents are further characterized by their physiological action and are discussed in detail in their individual chapters. Table 4-1 lists the major chemical warfare agents.

Nerve agents such as tabun (GA), sarin (GB), soman (GD), and VX inhibit acetylcholinesterase enzyme throughout the body, notably in the nervous system. This causes hyperactivation of cholinergic pathways, causing convulsive seizures and respiratory failure. VX differs from its "G" agent counterparts in its low volatility.

Vesicants, such as sulfur mustard (HD) and the arsenical Lewisite (L), cause irritation and vesication of the skin and mucous membranes, notably of the lungs. Mustard exposure to the skin is insidious, causing no immediate discernible effects to the skin for several hours; blistering occurs 12 to 24 hours after exposure.<sup>25</sup> Although mustard causes few deaths, its vesicating properties are incapacitating, and casualties require 1 to 4 months of hospitalization. Lewisite blisters heal within several weeks.

Pulmonary toxicants, such as phosgene (CG) and diphosgene (DP), injure the respiratory tract, causing suffocation. Phosgene intoxication rapidly leads to pulmonary edema. The initial effects of eye exposure resemble those of tear gas; severe pulmonary edema follows in about 4 hours, eventually leading to death. It is notable that both phosgene and elemental chlorine (an immediate phosgene precursor), which can cause pulmonary edema and hemorrhaging, are industrial compounds.

Finally, cyanides such as hydrogen cyanide (AC) and cyanogen chloride (CK) both release cyanide ions in the body. Lower doses cause headaches, weakness, disorientation, and nausea; higher doses cause circulatory effects, seizures, and respiratory and cardiac failure. While often attributed to its blockade of energy metabolism, the mechanisms of cyanide intoxication remain unclear and may include cellular targets more sensitive to inhibition than cytochrome oxidase.

The most common agents in modern arsenals are vesicants and nerve agents. Cyanides and pulmonary toxicants are thought to be represented in some stockpiles, but are typically less toxic and more difficult to employ because of their physical characteristics. Some cyanides and pulmonary toxicants have specific characteristics that make them appropriate for military use, such as rapid rate of action, very low persistency, and the ability to penetrate or damage protective equipment.

Other chemicals present in military arsenals include incapacitating agents, which produce physiological or mental effects, or both, rendering individuals incapable of performing their assigned duties. Recovery may take several hours to several days, although intensive medical treatment may not be required. Riot control agents produce intense effects, such as irritation of the skin, eyes, and respiratory tract, but recovery is normally rapid when exposure is terminated. Unfortunately, little is known about the long-term effects of many of these agents, and this is an area of increasing medical concern.

Chemical smoke agents are used to obscure objects or areas from observation or from engagement by weapons with electro-optical control systems. They are usually not toxic in field concentrations, but may cause eye or respiratory irritation in higher concentrations. Some smokes have adverse chronic exposure effects. Other compounds with military

**TABLE 4-1**  
**CHEMICAL WARFARE AGENTS**

U.S. Army Code	Agent
Cyanides	
AC	Hydrogen cyanide
CK	Cyanogen chloride
Nerve Agents	
GA (Tabun)	Ethyl N,N-dimethyl-phosphoramidocyanide
GB (Sarin)	Isopropyl-methylphosphonofluoride
GD (Soman)	1,2,2-Trimethylpropyl methylphosphonofluoride
GF	Cyclohexyl-methylphosphonofluoride
VX	<i>o</i> -Ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothiolate
Lung Toxicants	
CG (Phosgene)	Carbonyl chloride
DP (Diphosgene)	Trichloromethyl chloroformate
Vesicants	
HD (Mustard)	bis-2-Chloroethyl sulfide
L (Lewisite)	2-Chlorovinyl dichloroarsine
HL	Mustard-Lewisite mixture
Incapacitating Agent	
BZ	3-Quinuclidinyl benzilate (QNB)
Tear Gases	
CN	2-Chloro-1-phenylethanone
CS	2-Chlorobenzalmalononitrile
Vomiting Gas	
DM (Adamsite)	10-Chloro-5,10-dihydrophenarsazine

applications include agents used in flame warfare, such as thickeners for napalm and incendiary materials, and herbicides (defoliants).

Thus far, discussion has centered on chemical compounds with a military application. Other highly toxic industrial chemicals also pose a potential risk to the military. The disaster in Bhopal, India, in December 1984, when an estimated 8,000 persons died and another 30,000 were injured from breathing methylisocyanate and chlorine released in an industrial accident, is just one of many examples of the devastating effect of poisonous gases.<sup>26</sup>

Chlorine and phosgene are industrial compounds that have been and could again be used as military weapons by an enemy with access to such materials, and medical personnel should also be prepared for such emergencies should military missions be in close proximity to industrial plants. The first large-scale use of a chemical compound in Ypres, Belgium, on 22 April 1915, the beginning of chemical warfare as we know it today, involved the dispersal of 180 tons of chlorine from over 5,700 canisters by the German forces. During that war, the list of chemical agents was expanded to include mustard, phosgene, adamsite, and cyanide.

## TACTICAL AND STRATEGIC USE OF CHEMICAL WEAPONS

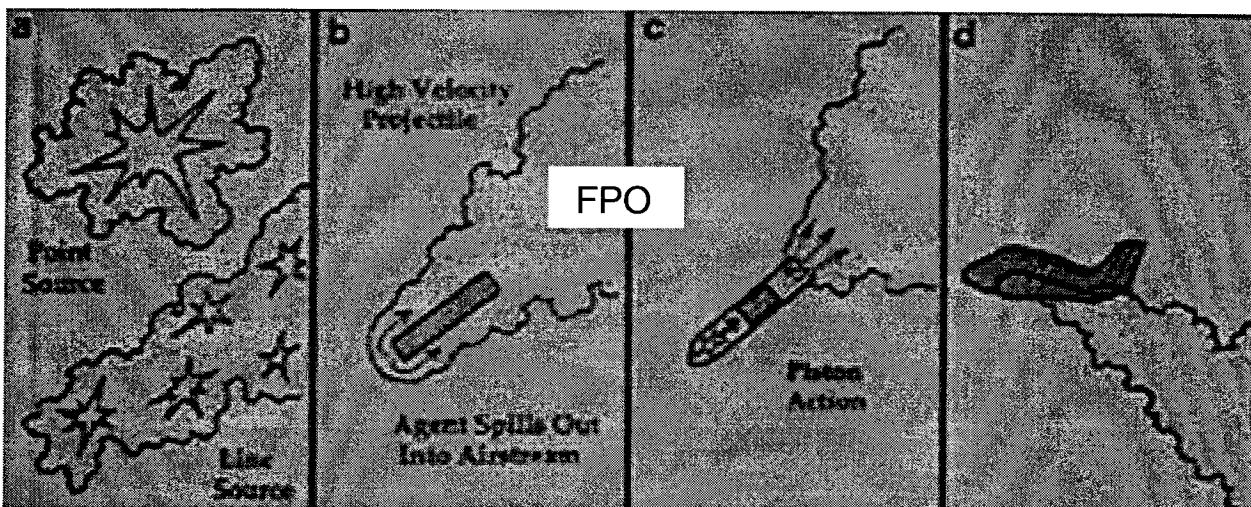
Delivery of chemical agents can be accomplished by a full range of weaponry. Liquid agents may be dispensed from land mines and spray tanks to artillery projectiles, aerial bombs, rocket and missile warheads, or even cruise missiles. This means that all battlefield areas, from front lines to rear reserves, are vulnerable to chemical warfare attack, and that medical practitioners should be fully prepared to treat chemical warfare casualties from a variety of locations. It is also important to note that, while this section largely focuses on the use of chemical warfare agents on the battlefield, medical personnel must also be prepared for the possibility of isolated and spontaneous chemical attacks on both military personnel and civilians in areas subject to low-intensity conflict and isolated acts of terrorism.

To be effective, chemical agents must be efficiently dispersed over their intended targets. Most applications call for large-scale agent distribution over large target areas that are occupied by, or may be of interest to, military units. For example, documents recovered from the former German Demo-

cratic Republic called for Warsaw Pact forces to employ heavy chemical warfare attacks early in any conflict with the West.<sup>23</sup> Considerable quantities of an agent may have to be applied to ensure good coverage in the face of such factors as wind, heat, and agent volatility, and surprising the enemy so as to find them unprotected (eg, unmasked).

### Chemical Agent Delivery Systems

The four methods of delivering chemical agents are explosive release, bulk release, base ejection, and spray delivery (Figure 4-1). The most common method is explosive release. Bursts from individual explosive munitions are, effectively, point sources for chemical warfare dissemination. Chemical warfare artillery shells, which serve as smaller point sources, could be laid down in a grid to cover a large area. The same could be accomplished with fewer missiles, which carry larger payloads and have longer ranges. Agents can also be delivered from multiple explosive point sources using submuni-



**Fig. 4-1.** Four modes of chemical agent release. (a) Explosive-release devices are predominantly represented among the major chemical warfare arsenals. While some agent is lost to decomposition, their simplicity makes these the weapons of choice. Point-source explosives are single detonation devices, while line-source munitions release a series of time-delayed explosions that lay agent toward the end of the trajectory. (b) Bulk-release munitions spill agent into the airstream of the projectile. (c) Base-ejection devices are relatively uncommon owing to their cost and complexity. Like explosives and bulk-release devices, these munitions can be carried on longer-range missiles. (d) Spray delivery can be used to achieve large-area coverage, such as that required for terrain denial. However, because of aircraft vulnerability, spray delivery is generally limited to application on undefended territory or against a poorly defended foe.

tions to cover a larger area or, if detonated in sequence, to lay down the agent along a trajectory line. Such line deliveries may be delivered directly over the target, or upwind of the target, preferably perpendicular to the wind.

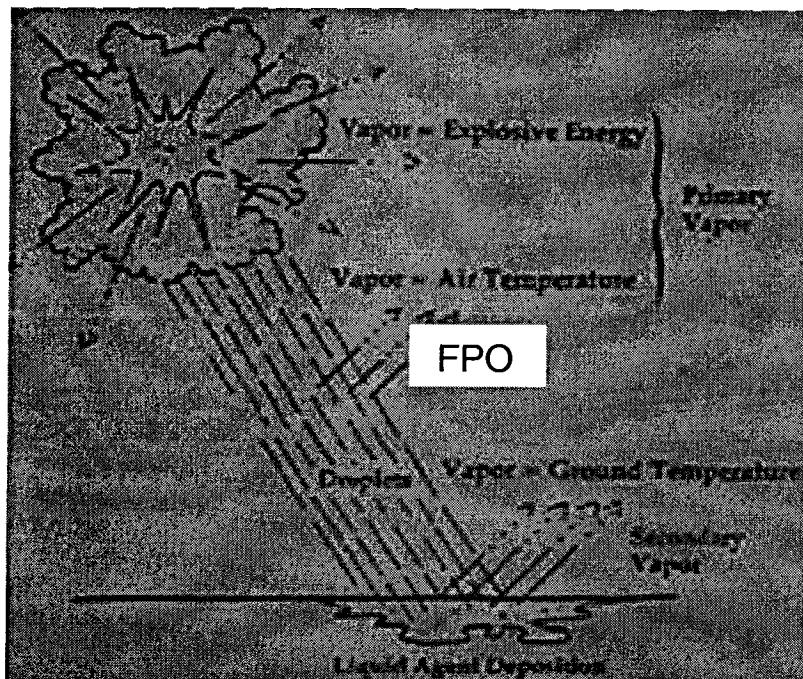
Bulk release, base ejection, and spray delivery also deliver chemical warfare agents along trajectory lines. In bulk release, the forward covering, or "skin," of a warhead is blown off, exposing agent to aerodynamic breakup by high-speed air flow. In base ejection, an explosive charge causes an internal pistonlike action to force the agent out of the back of the warhead—either through small apertures, aerosolizing it, or into a high-speed airstream for aerodynamic breakup. Explosive, bulk release, and base ejection methods are primarily suited for the dispersal of liquid chemical agents. For the few solid agents such as the tear gas CS and the incapacitating agent BZ (3-quinuclidinyl benzilate), effective aerosolization is often achieved by pyrotechnic munitions.

Spray delivery is more efficient than the other three methods in providing a very fine aerosolization (average droplet diameter =  $< 5 \mu\text{m}$ ) of agent, which can be inhaled far down into the lungs. This method is particularly suited to the delivery of toxins, which require deep inhalation and which differ from most chemical agents in that they are

solids and do not vaporize. Spray delivery requires slow speeds and low altitudes, conditions that render aircraft particularly vulnerable to attack. Spray tanks could also be mounted on trucks or boats, and unmanned aircraft could be designed to perform the task. The increased vulnerability of spray-delivery systems makes their use more likely against unarmed or poorly equipped opponents, or on carefully targeted sites under cover of surprise. Spray delivery could also be applied to closed ventilation systems in more focal applications.

From a tactical military standpoint, explosive munitions, the dominant mode of chemical agent delivery, vary with respect to effective agent delivery. Disregarding differences among chemical warfare agents for now, Figure 4-2 describes chemical agent dissemination with respect to explosive munitions in further detail and illustrates important considerations regarding the chemical agent dynamics and toxicity. Explosion of a chemical agent shell, at ground level or some height over the target site, generates two products: vapor and droplets. Droplets (average diameter range = 100  $\mu\text{m}$  to 1 mm for pure agents) will fall to the ground in a fine rain to coat the target surface with liquid.

Agent vapor, the greatest threat for inhalational intoxication, derives from three sources. First, agent vaporizes from explosive burst energy. This will



**Fig. 4-2.** Agent vaporization increases in proportion to energy sources such as heat from explosive charges or from ambient heat (as measured by air or surface temperatures). Vapor persistence is then determined by weather factors such as wind and humidity. Hydrolysis rates are affected by factors such as temperature and solubility. Agents show characteristic hydrolysis rates in water, and water vapor, as described by humidity, may cause significant hydrolysis of vaporized agent. The vesicant Lewisite, for example, shows relatively rapid hydrolysis in water vapor, while the nerve agent VX is more resistant to hydrolysis.

vary with shell design and specific agent payload. Important shell design factors are shell casing thickness, shell casing material, and the agent-to-burster ratio. Second, additional vapor will be generated as falling droplets vaporize. Heat from the explosion dissipates quickly, and ambient air temperature is the most important factor in driving this volatilization. Third, the liquid coating of agent on the ground evaporates, ground temperature being an important factor. Vapor produced by the first two, explosive energy and droplet vaporization, is called primary vaporization, while that rising from the ground is secondary.

Considering these phenomena, we can appreciate, for example, the differences in agent threat (liquid persistence and deposition vs vaporization) in scenarios wherein chemical agent shells are dropped on a desert area during different times of the day. The influence of wide environmental temperature fluctuations over the 24-hour cycle, combined with the agent used (see below) can make a large difference: we can expect increased surface deposition and skin-contact threat during cool nights, and a considerably increased inhalational toxicity threat during the heat of the day.

Successful employment of chemical agents is influenced by many variables. Most notable among these is the weather, in that the agent is transported by the wind and air currents when released as a vapor or an aerosol. Unfavorable meteorological conditions frequently preclude successful agent deployment owing to the inordinately high number of weapons used. Once deployed, the persistence of liquid contamination is affected by temperature, sunlight, wind action, and rainfall.

### Physical Properties of Chemical Agents

Toxicity mechanisms aside, the physical properties of the agent itself and its formulation also present similarly important threat considerations. Selection of agents and agent formulations can be used to effect differential impacts with respect to droplet size and liquid deposition, agent persistence, and agent volatility. The classic chemical warfare agents have a tremendous range of volatility (Table 4-2), and volatility can be a determinant in deciding which agents will be used.<sup>27</sup> Agents such as hydrogen cyanide and sarin are relatively volatile; they present an immediate, but short-lived, threat. These agents are referred to as nonpersistent (ie, they vaporize rapidly after delivery). Alternatively, agents such as VX and sulfur mustard tend

**TABLE 4-2**  
**COMPARATIVE VOLATILITIES OF CHEMICAL WARFARE AGENTS**

Agent	Volatility * (mg/m <sup>3</sup> )
Hydrogen Cyanide	1,000,000
Sarin (GB)	22,000
Soman (GD)	3,900
Sulfur Mustard (HD)	900
Tabun (GA)	610
VX	10

\*Approximate amount of agent (in milligrams) that 1 m<sup>3</sup> of air can hold at 25°C.

Adapted from US Departments of the Army, Navy, and Air Force. *Potential Military Chemical/Biological Agents and Compounds*. Washington, DC: Headquarters, DA, DN, DAF; 12 Dec 1990: Appendix B, Table B, pp 95–97. Field Manual 3-9. Naval Facility Command P-467. Air Force Regulation 355-7.

to fall largely in droplets, with less vaporization, and remain on exposed surfaces for a long time. These agents are called persistent.

Formulation is also used to manipulate the fate of the agent. Soman, VX, Lewisite, and sulfur mustard can be mixed with high-molecular-weight thickeners to increase droplet size and thereby decrease primary vaporization. Such additives are generally used to promote efficient agent deposition on the target site. Thickeners can also increase agent persistence and may hamper decontamination efforts.

### Nonpersistent Agents

In tactical use, the threat of nonpersistent, volatile agents such as hydrogen cyanide or sarin is greatest to the respiratory systems of unprotected soldiers. A sudden, heavy bombardment of these agents may effect many casualties if unmasked soldiers are caught by surprise. When used against an unprotected force, nonpersistent agents are particularly effective in generating casualties, thereby creating breakthrough points in enemy front lines. The successful use of nonpersistent nerve agent was demonstrated by Iraqi counterattacks against Iranian forces during 1988.<sup>23</sup> Nonpersistent agents can also be used to slow down the

enemy by forcing him to wear protective equipment. Finally, they can also circumvent the enemy's protection against conventional high-explosive munitions and may be used in night attacks to harass the enemy.

### Persistent Agents

Given favorable weather conditions, the use of persistent agents such as mustard and VX may pose a threat for many days. Such agents can deny or interfere with enemy occupation of terrain or use of equipment and, in theory, could be used defensively to protect vulnerable flanks. However, although they can slow down enemy movement, they can also hamper the movement of friendly forces through a contaminated area. Delayed casualties may occur even among protected troops operating in a contaminated area for an extended period. Hence, persistent agents may not be the agents of choice when occupation of territory by friendly forces is imminent.

Chemical land mines may be used in conjunction with military barrier systems to complicate breaching or clearing the barriers by dispersing persistent agent. The mines are typically based on high-explosive mine designs, with several pounds of agent being substituted for most of the explosive charge. High-explosive land mines will cause contaminated open wounds, primarily on lower extremities, that must be properly decontaminated; this could be more difficult when persistent agents are used.

Because of its action, sulfur mustard blistering agent offers strategic benefits besides those considered above. Sulfur mustard was used very effectively both during World War I and during the Iran-Iraq War to generate thousands of casualties. Although deaths among unprotected sulfur mustard exposure victims are relatively few,<sup>28</sup> mustard injuries can tie up medical treatment facilities with patients. While survivors of other agents stabilize relatively soon after exposure, mustard lesions demand months of medical care. This was the fate of many thousands of Iranian recruits, who were unprepared or poorly equipped when they were exposed to sulfur mustard agent.

Underscoring the importance of ambient temperature and climate, we should note that persistence can change greatly with temperature; sulfur mustard volatility increases nearly 40-fold between 0°C and 40°C: from 75 to 2,860 mg/m<sup>3</sup>. Although always present, the threat of respiratory in-

toxication from sulfur mustard is considerably greater at higher temperatures, although its persistence is reduced.

Rapidity of action also factors into agent selection. Volatile agents such as cyanide and sarin can act very swiftly, primarily via the respiratory tract. In general, nerve agent effects follow immediately after exposure, culminating in seizures and death within a few minutes of inhalation, cutaneous dosing, or both. Other agents, such as mustard, Lewisite, and phosgene act only after a delay. For example, both the blistering and the edematous effects of skin exposure to sulfur mustard occur only many hours after exposure.

### Choice of Agent and Delivery System

By selecting the appropriate agents, formulations, and delivery systems, a well-equipped military will be in a better position to achieve its tactical objectives. U.S. Army Field Manual (FM) 3-10, *Employment of Chemical Agents*, discusses how chemical munitions could be used separately or integrated with conventional weapons. Chemical warfare agents can be used to cause casualties, harass the enemy, and hamper or restrict the use of terrain. Although an offensive capability no longer exists, FM 3-10 provides useful information on how chemical warfare agents can be used on the battlefield.<sup>29</sup> Brigadier General Augustin M. Prentiss, a Chemical Warfare Service officer, describes in his classic 1937 book, *Chemicals in War*, the offensive tactical uses of chemical agents that were in place following World War I.<sup>30</sup>

The most militarily significant effects of chemical agents are through inhalation, in that most agents are more toxic and faster acting by that route of exposure. Almost without exception, modern armies are equipped with protective equipment: masks to protect the eyes and respiratory tract, and protective clothing to prevent skin contamination. However, the very act of donning protective equipment is an encumbrance. In hot weather, remaining in protective clothing for more than a few minutes can itself produce casualties. The mission-oriented protective posture gear (MOPP) that the U.S. Army issues, which was designed for use in the European theater, can swiftly cause an active wearer to experience heat stress and dehydration under desert conditions.<sup>31,32</sup> The British protective counterpart, the MK 4 suit, keeps the wearer cooler by allowing perspiration to evaporate, although the heat stress problem remains.<sup>33</sup>

## Detection and Protection

Adequate agent detection capabilities are essential for successful chemical agent defense. Although U.S. Army doctrine prescribes donning full MOPP 4 gear if an attack is imminent or in progress, detection capabilities permit recognition of the true agent threat and appropriate reductions to protective posture (ie, MOPP 3 or even MOPP 2). Detection capability for medical teams is essential to provide warning that casualties are contaminated, and to avoid inappropriate assumption of high levels of protective posture if they are not.

Well-equipped, well-trained troops who apply high levels of discipline in using protective equipment are not very likely to become chemical casualties. Most casualties will have sustained respiratory injury due to failure to mask properly in time when under attack. We can speculate that as the length of time spent in protective posture increases, the percentages of casualties with skin effects will increase. Most of these effects will be from failures

in procedure when donning protective clothing and removing contaminated protective clothing.

Among exposed populations, the range of agent intoxication effects can be expected to correlate with levels of protective equipment, training, and discipline. The healthcare provider should anticipate that poorly trained soldiers will show an increased incidence of skin contamination by vesicants, for example. There will also be a greater need for decontamination. Civilian populations will generally be the most vulnerable. Most will have little if any protective equipment, and no means of detecting the presence of agent.

Even with protective equipment, the threat of agent intoxication is greater for casualties with facial, neck, or chest wounds that may compromise the integrity of the protective mask seal. Based on wound descriptions, a retrospective analysis<sup>34</sup> of 2,021 casualties admitted to the Naval Support Hospital in Da Nang, Vietnam, found that mask failure could have been expected to affect 34% of these patients.

## RESPONDING TO THE THREAT: MANAGING CASUALTIES

The medical management of casualties, including triage, decontamination, and specific therapy, is discussed in separate chapters. However, several points need emphasis under a discussion of concerns for the healthcare provider.

First, many of the early signs and symptoms produced by chemical warfare agents may resemble those of a variety of disorders, including stress. Among unseasoned troops, especially those with limited experience in a chemical environment, psychological withdrawal or physical complaints of palpitation, gastrointestinal distress, headaches, dizziness, and inattentiveness will present difficult diagnostic dilemmas for medical personnel on the battlefield. A clinical awareness of the early signs and symptoms is critically important, but so is an awareness of the medical problems associated with stress. The potential for mass hysteria is also high, even among troops with full individual protection, and the horror of dying from a chemical agent attack is widespread. Apprehension will be a major factor in the confusion of battle.

To minimize such problems, continuous training is required so that soldiers are comfortable donning their protective equipment and operating in a chemically contaminated environment. Similarly, soldiers must understand the rationale for taking the nerve agent pretreatment, pyridostigmine, as an

added protective measure, not as a replacement for masking. Such training should involve medical input.

Second, the risk of chemical contamination of medical equipment and medical treatment facilities is an added threat, and precautions need to be taken to ensure that patients are properly decontaminated before being brought into designated uncontaminated treatment areas. Frontline medics faced with many casualties can only be expected to administer lifesaving procedures, such as opening the airway or preventing further hemorrhage; decontamination can be expected to be minimal.

In rear areas, chemical decontamination of open wounds adds substantial complexity to otherwise conventional wounds, which then require procedures different from those ordinarily established for debridement. Some nations have adopted special irrigation-suction devices to irrigate and clean wounds, and air-flow protection methods to minimize the risk to hospital staff. The risk of wound contamination may be higher with low-velocity wounds, when pieces of contaminated clothing or debris may be carried into the wound and remain deeply imbedded for a time; this may be a greater problem with persistent agents. Therefore medical procedures must be well defined, and healthcare providers should regularly review the steps required in handling a casualty.

While chemical agents are an occupational hazard to the combat soldier, they are also a danger to the emergency room and surgical staff, who must rely on their hands and eyes to stabilize and treat the casualty. Standard surgical latex gloves are not sufficient protection against chemical agents, and they provide little protection against a vapor hazard. Should hospital-based medical personnel in critical specialties become casualties themselves, the healthcare delivery system will be significantly compromised. An improperly decontaminated casualty may also pose a risk to other patients.

Third, the patient flow pattern in a chemical environment will be substantially altered. Treatment rates can be expected to be reduced because of the decontamination procedures that must be in place. Injuries that will be seen will range from severe to minor, with the latter probably constituting the majority. With some agents, the effects of chemical injury may not be readily apparent until after a de-

lay, and this must be considered in the disposition of the patient. Therefore, the process of medical evaluation and observation may tax the holding capability of a facility.

Finally, the medical logistical requirements will be increased. It has been stated that up to 40% more transport is required to move a typical field hospital in a chemical environment, and the fuel necessary to power air pumps, special filtration units, and air conditioners is an added requirement.<sup>35</sup> Water requirements may also be increased in a chemical environment. Medical treatment facility planners should recognize the importance of environmental factors within a chemical warfare theater. For example, the MOPP gear may not be designed for the climatic conditions on the battlefield. Tests have shown that perspiration compromises the ability of the battledress overgarment to protect the wearer from chemical agents<sup>36</sup> and may actually predispose an individual to injury.<sup>32</sup>

## FUTURE CONFLICTS IN A CHEMICAL ENVIRONMENT

From the standpoint of military strategy, two reasons are commonly cited for a combatant to employ chemical weapons. First, they can be highly effective when densely applied onto concentrated, largely immobile forces or populations. This factor largely promoted their use against entrenched troop positions during World War I. During the Cold War, military strategists anticipated similar intense chemical warfare bombardments from Warsaw Pact forces in the European theater. Second, chemical attacks can be initiated at lower levels to encumber an opponent with defensive equipment, or to create panic and disorder among poorly trained or unprepared troops. Application onto enemy troops or civilian populations can also have a strong demoralizing effect.

Two important influences on the decision to employ chemical attacks are weather patterns and user objectives. Gas dispersal depends on wind speed and direction. If the attacking force is in close proximity to the target area, it must use protective gear in the event of wind shift. This handicap can be avoided, if the situation allows, when agents can be delivered from a remote location by either air or long-range artillery. The objectives of an attacker may also determine whether chemical warfare will be employed and, if so, which agents are to be used. Thickened nerve agents and sulfur mustard deny free access to terrain and are not likely to be used by forces intent on occupation. Nonthickened nerve

agents are not persistent and could be used by a mobile, advancing force.

Western powers had contemplated using chemical weapons during World War II. Sir Winston Churchill seriously contemplated resorting to chemical warfare should the defense of Britain have become desperate.<sup>37</sup> Later in the war, U.S. military commanders also contemplated the use of chemical agents to counter Japanese fanaticism, which, even during imminent defeat in 1945, caused exceedingly high losses on both sides during island warfare (nearly 110,000 Japanese died in the battle for Okinawa alone). These circumstances led the United States to resort to unconventional weaponry (the atomic bomb). With Germany out of the war and the death of President Roosevelt, who had opposed any first use of chemical weapons, the use of sulfur mustard and other agents was seriously contemplated during the summer of 1945.<sup>38</sup> Based on recent events and decisions, however, it is unlikely that an offensive chemical warfare program would be initiated by Western powers. This does not negate the need for a strong defense posture, however, as long as chemical proliferation continues.

Fanaticism shown by Iranian Revolutionary Guard units may have precipitated Iraqi use of chemical warfare agents at the end of 1983. Throughout the Iran-Iraq War, Iraq generally used chemical weapons only when facing probable defeat with conventional weapons.<sup>39</sup> History suggests

that a cornered and besieged enemy, confronting troops intent on inducing complete surrender, could employ chemical warfare agents as a final resort or act of vengeance. In 1937, Prentiss stated:

In the last analysis, war is not a sport, but a grim contest between states for national existence. War

cannot be conducted by any code of sportsmanship, but only by the law of military necessity, however much civilization may deplore the results.<sup>31(p699)</sup>

Therefore, the United States military must maintain a strong readiness posture in the face of a continuing chemical warfare threat.

## SUMMARY

The military healthcare provider should be prepared to be the first to recognize military or civilian casualties of chemical warfare attack. This requires an informed understanding of the likelihood of chemical warfare agent use or threat, and it requires the ability to clearly recognize agent-exposure symptoms against a varying background of unrelated injury and stress behaviors. The healthcare provider should be informed, to the fullest extent possible, when to anticipate chemical warfare attack by hostile forces or terrorist activities. This requires consideration of an adversary with regard to political factors and motivation, chemical agent possession or access, chemical warfare offensive

and defensive capabilities, and the strategic advantage to be realized through agent use.

When individuals suspected to have been exposed to chemical warfare agents are encountered, initial recognition of the type of agent used may be facilitated through an understanding of tactical agent use, modes of agent dissemination, likely routes of casualty exposure to agent, and physical agent properties and other factors determining the persistence of these toxicants in the operating environment. Finally, to protect both the injured and medical personnel, casualty care must take place within a framework of decontamination both in the field and in forward medical support facilities.

## REFERENCES

1. Burck G, Flowertree CC. *International Handbook on Chemical Weapons Proliferation*. New York, NY: Greenwood Press; 1991: 3-4, 164-171.
2. Smith J. Confusing data on chemical capability: US intelligence, diplomatic lists of armed nations differ. *Washington Post*. 15 Mar 1991;A21.
3. Browder G, chairman. *Countering the Chemical and Biological Weapons Threat in the Post-Soviet World*. Report of the special inquiry into the chemical and biological threat of the Committee on Armed Services, US House of Representatives, 102nd Congress (2nd Session). Washington, DC: US Government Printing Office; 23 Feb 1993. ISBN 0-16-040163-1.
4. Evans D, Bailey K, Lambakis S, Rudney B, Victory B. *Iraqi Inspections: Lessons Learned*. Washington, DC: Defense Nuclear Agency; 1992. Unclassified Technical Report. DTIC B170991.
5. Ember E. Chemical arms treaty ratification moves forward. *Chemical and Engineering News*. 1993;70(47):14-15.
6. Mathewson W. Soviets' chemical weapons. *Wall Street Journal*. 3 Aug 1990:A10.
7. Ember E. Russia seeks US expertise, money to destroy its chemical arms. *Chemical and Engineering News*. 1992;71(4):18-19.
8. Felten E. Amid discontent, weapons could fall into unsafe hands. *Washington Times (Insight)*. 29 Oct 1990;26-27.
9. Segal D. The Soviet Union's mighty chemical warfare machine. *Army*. Aug 1987;37(8):26-35, 38.
10. Mohr H. Chemical weapons out of control. *Washington Times*. 17 Oct 1989;F3.
11. Livingstone NC, Douglass JD. *Chemical and Biological Weapons: The Poor Man's Atomic Bomb*. Cambridge, Mass: Institute for Foreign Policy Analysis; 1 Feb 1984. National Security Paper 1.

12. Nolan JE, Wheelon AD. Third World ballistic missiles. *Sci Am.* 1990;263(2):34–40.
13. Kempster N. For the Middle East, arms control is no longer unthinkable. *Los Angeles Times.* 1 May 1990;H5.
14. Windrem R. Iraq's most lethal weapons. *Popular Science.* Feb 1991;238(2):51–55, 84.
15. Rathmell A. Chemical weapons in the Middle East: Syria, Iraq, and Libya. *Marine Corps Gazette.* July 1990;59.
16. Timmerman KR. The poison gas connection: Western suppliers of unconventional weapons and technologies to Iraq and Libya. Los Angeles, Calif: Simon Weisenthal Center; 1990. Special Report.
17. Felton J. Approval seen on chemical weapons. *Congressional Quarterly Weekly Report.* 9 June 1990;48(23):1800.
18. The Committee on Armed Services, US House of Representatives. Countering the chemical and biological weapons threat in the post-Soviet world. Report of the Special Inquiry Into the Chemical and Biological Threat. Washington, DC: US Government Printing Office; 23 Feb 1993.
19. Towell P. In the bag: Chemical weapons pact. *Congressional Quarterly.* 26 May 1990;48(21):1664.
20. Smith RJ, Yang YE. Bush to scrap all US chemical arms. *Washington Post.* 14 May 1991;114(160)A-1, A-12.
21. Browder G, chairman. *Countering the Chemical and Biological Weapons Threat in the Post-Soviet World.* Report of the special inquiry into the chemical and biological threat of the Committee on Armed Services, US House of Representatives, 102nd Congress. Washington, DC: US. Government Printing Office; 23 Feb 1993: 9. ISBN 0-16-040163.
22. Wilkinson P. Terrorism, Iran and the Gulf region. *Jane's Intelligence Review.* 1992;4(5):222–226.
23. US Army Chemical School. World-wide NBC threat briefing. Fort McClellan, Ala: US Army Chemical School Threat Office; March 1992. Unclassified.
24. Agence France Presse. Cyanide stolen in Kyrgyzstan. *Agence Presse English Wire.* 25 September 1992.
25. Papirmeister B. A global picture of battlefield vesicants, I: A comparison of properties and effects. *Medical Chemical Defense.* 1992;5(1):1–8.
26. Kurzman D. *A Killing Wind: Inside Union Carbide and the Bhopal Catastrophe.* New York, NY: McGraw-Hill; 1987.
27. US Departments of the Army, Navy, and Air Force. *Potential Military Chemical/Biological Agents and Compounds.* Washington, DC: Headquarters, DA, DN, DAF; 12 December 90. Field Manual 3-9. Naval Facility Command P-467. Air Force Regulation 355-7.
28. Gilchrist HL. Statistical consideration of gas casualties. In: Weed FW, ed. *Medical Aspects of Gas Warfare.* Vol 14. In: Ireland MW. *The Medical Department of the United States Army in the World War.* Washington, DC: US Government Printing Office. 1926: 273–279.
29. US Departments of the Army, Navy, and Air Force. *Employment of Chemical Agents.* Washington, DC: Headquarters, DA, DN, DAF; Mar 1966. Field Manual 3-10. Naval Warfare Information Publication 36-2. Air Force Manual 355-4. Fleet Marine Force Manual 11-3.
30. Prentiss AM. *Chemicals in War.* New York, NY: McGraw-Hill; 1937.
31. 60 Minutes. Likely effects of Iraqi chemical weapons attack. *Columbia Broadcasting System.* 26 Aug 1990.
32. Carter BJ, Cammermeyer M. Emergence of real casualties during simulated chemical warfare environment. *Milit Med.* 1985;150(12):657–665.

33. Harrington L. US lightens up for chemical fight. *Chicago Tribune*. 26 November 1990;14.
34. McCaughey BG, Garrick J, Kelly JB. Combat casualties in a conventional and chemical warfare environment. *Milit Med*. 1988;153 (5):227-229.
35. Hammick M. The chemical question. In: The cutting edge: Battlefield casualty management. *International Defense Review*. Mar 1992;25(3):250-251.
36. Greve F. US troops ill-equipped for desert gas warfare. *Philadelphia Inquirer*. 9 Aug 1990;1.
37. Taylor LB, Taylor CL. *Chemical and Biological Warfare*. New York, NY: Franklin Watts Press; 1985.
38. Van Courtland Moon JE. Project SPHINX: The question of the use of gas in the planned invasion of Japan. *Journal of Strategic Studies*. September 1989;12(3):303-323.
39. Morrison DC. Chemical fears exaggerated. *National Journal*. 8 September 1990;22(36):2133.